BMJ Open

Current applications of indocyanine green fluorescence angiography in trauma patients and its potential impact: a systematic review

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To cite: Breuking EA, de Fraiture EJ, Krijgh DD, *et al*. Current applications of indocyanine green fluorescence angiography in trauma patients and its potential impact: a systematic review. *BMJ Open* 2025;**15**:e099755. doi:10.1136/bmjopen-2025-099755

► Prepublication history and additional supplemental material for this paper are available online. To view these files, please visit the journal online (https://doi.org/10.1136/bmjopen-2025-099755).

Received 24 January 2025
Accepted 02 May 2025

Check for updates

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ABSTRACT

Objectives Tissue viability assessment is one of the main challenges in trauma surgery. Vitality assessment using indocyanine green fluorescence angiography (ICG-FA) may improve surgical decision-making. This systematic review gives an overview of current applications of ICG-FA in surgical treatment of traumatic injury and its effects on the incidence of postoperative complications and intraoperative decision-making.

Design Systematic review according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines.

Data sources PubMed, EMBASE and MEDLINE were searched through 18 December 2023.

Eligibility criteria for selecting studies Primary research reports regarding indocyanine green (ICG)-fluorescence in patients with traumatic injury were included. Exclusion criteria were use of ICG for treatment of burn wounds, traumatic brain injury or reconstructive surgery, absence of an English or Dutch full-text and non-primary study design.

Data extraction and synthesis Two independent reviewers performed the search and screening process according to standardised methods. Risk of bias was assessed using the Methodological Index for Non-Randomised Studies. Data were presented in text and overview tables.

Results Thirteen studies were included, of which six were case series/reports including three or fewer patients. Within the other seven studies, 301 patients received ICG-guided surgery. ICG was used for perfusion assessment in all studies. Injury types consisted of traumatic extremity and abdominal injury. All studies reported beneficial effects such as necrosis detection, determination of resection/debridement margins and reduction of debridement procedures. ICG could improve intraoperative decision-making and significantly decrease postoperative complications. No included studies reported ICG-related complications or adverse events.

Conclusion The available literature regarding the use of ICG-FA in trauma surgery is limited, and comparability is low. Still, the results are promising and show a large potential of ICG-FA for better and more efficient treatment of trauma patients. Further research with larger samples and comparable conditions is thus necessary and highly recommended.

STRENGTHS AND LIMITATIONS OF THIS STUDY

- ⇒ This review provides a comprehensive overview of current indocyanine green (ICG) applications in trauma surgery and their impact on clinical outcomes.
- ⇒ As the use of indocyanine green fluorescence angiography is still quite new to trauma surgery, this review also highlights practical differences between studies, emphasising the need for standardisation in this emerging field.
- ⇒ The heterogeneity in study design, ICG dosage, timing and use of mostly qualitative or limited quantitative outcomes hinders validation and precludes meta-analysis.
- ⇒ Due to the limited availability of studies, data from different trauma types (eg, abdominal and extremity trauma) were combined, which may reduce specificity.
- ⇒ This systematic review is subject to a high risk of bias due to the retrospective, non-randomised nature of most studies and potential publication bias favouring positive findings.

BACKGROUND

One of the main challenges in trauma surgery is the assessment of tissue viability. During initial management, it is essential to identify margins that need to be resected as well as tissue that can be spared. This has to be done under time pressure as the risk of necrosis, infection and complications increases with a delay in intervention.[1 2] Most patients require multiple surgical interventions with a high risk of postoperative infection, such as soft tissue debridement, stump revision or definitive reconstruction after damage control (DC) surgery.

Although functional limb salvage is the ideal outcome, surgeons need to consider the high risk of complications when trying to save as much tissue as possible. In post-traumatic single limb amputations, Barmparas *et al* described a complication rate of 26% with a stump revision rate of 38%.[3] Low *et al* found even higher rates in lower limb amputees: 28% of patients had major postsurgical complications and 42% needed stump revision. Patients with crush injury had an increased chance of revision amputation compared with other injury types. Moreover, the presence of major postsurgical complications was a significant predictor of in-hospital mortality, which almost doubled the odds.[2] These complications thus not only impose a physical burden for patients but also an economical and practical burden for the system. For example, surgical site infection (SSI) substantially increases the financial burden on total healthcare expenditure. This is mostly due to additional surgeries, extended hospital length of stay (HLOS), readmissions and extensive postoperative antibiotic treatment.[4] Likewise, revision amputation extends HLOS with >5 days.[2]

Similar arguments apply for definitive reconstruction after DC surgery in patients with abdominal trauma. DC surgery may be overused and often causes significant complications.[5] It has been reported that in over 80% of trauma patients treated with DC/open abdomen, SSI and intra-abdominal abscesses occur.[6–9] This high incidence depends, among other things, on the extent of traumatic injuries and/or bowel pathology such as perforation and ischaemia, as well as complications such as bile leakage.[10]

Indocyanine green fluorescence angiography (ICG-FA) can be used to visualise tissue perfusion in real time within a timeframe of minutes. When injected intravenously, the fluorescence agent indocyanine green (ICG) binds to plasma proteins that are confined to the intracellular compartment.[11] Since leakage of ICG into the interstitial space is minimal, this technique allows for high-quality images of microvasculature and soft tissue flaps.[12] Research has already shown that the intraoperative application of this technique can help reduce the risk of anastomotic leakage.[13 14] Moreover, it tends to improve surgical decision-making in colorectal surgery.[15 16] This technique may also be beneficial in trauma surgery, as it provides fast and real-time information which could assist in the critical and time-sensitive decision-making process. Even more, it could be beneficial in postsurgical care, for example, to determine the best timing for and level of stump revision or second-look surgery. Its feasibility for assessment of skin perfusion for the purpose of planning trauma surgery was already shown in 2006.[17] Although promising, these subjective interpretations of the fluorescence images lack the possibility of objectification and validation which is required for widespread implementation of ICG throughout trauma care. Furthermore, ICG can be used to detect bile leakage intraoperatively, as was shown in laparoscopic cholecystectomy, and can thus help to prevent further complications in the severely injured patient.[18]

To further explore the potential of ICG-FA in trauma surgery, it will first have to be established what is already known about its use and effects in trauma surgery. This study aims to give an overview of current applications of ICG-FA in the surgical treatment of traumatic injury, as well as its effect on the incidence of postoperative complications and intraoperative decision-making.

METHODS

This systematic review of the literature was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines.[19] An a priori study protocol was developed and registered in PROSPERO under registration number CRD42024538012.

Search and selection

A systematic search of PubMed, EMBASE and MEDLINE was conducted for studies published from inception up to 18 December 2023. The search syntaxes can be found in online supplemental 1. No search filters were applied. Two reviewers (EAB and EJdF) independently screened titles and abstracts for potential eligibility. Duplicates were removed. The full texts of potentially eligible articles were retrieved. If a full text was not available, it was attempted to retrieve it from the library or directly from the authors. Full-text reports were screened by two reviewers (EAB & EJdF), after which the eligibility of the remaining reports was assessed by reading them in full. Any disagreements were resolved by discussion with a third independent reviewer (JR).

All primary research studies reporting on any type of ICG fluorescence for interventional purposes in patients with a traumatic injury which caused a potential threat to tissue viability were included. Studies in which ICG was used for treatment of burn wounds, traumatic brain injury or reconstructive surgery were excluded. Only articles written in English or Dutch were included. All types of reviews, conference abstracts, expert meeting reports, study protocols, guidelines, discussions, letters, commentary, animal studies and cadaver studies were excluded.

Quality assessment

The quality of the included studies was assessed by two independent reviewers (EAB and EJdF). The assessment was performed using the Methodological Index for Non-Randomised Studies (MINORS), a validated score for the assessment of the methodological quality of non-randomised surgical studies ranging from 0 to 24. The higher the score, the better the methodological quality of the study.[20] Assessment criteria were clarified before the quality assessment was performed (online supplemental 2). Any disagreements between the reviewers were resolved by discussion with a third independent reviewer (JR).

Outcomes

The primary outcomes of this review were the frequency and types of application of ICG-FA (and similar ICG-based fluorescence techniques) in traumatic injury requiring surgical treatment. The secondary outcome was the impact of current applications of ICG-FA in traumatic injury requiring surgical treatment, specifically regarding postoperative complication rate and intraoperative decision-making.

Data extraction

The following data were collected from eligible studies: study design, number of patients, mean patient age, type of traumatic injury, purpose for which ICG was used, dose of ICG, whether a change in decision was indicated by ICG, postoperative outcome of included patients and complications or adverse events related to ICG. No automated tools were used for data extraction.

If possible, data were presented using descriptive statistics. Categorical variables were presented as frequencies and percentages. Continuous variables were presented as mean and SD. Data were converted into the same metric units. In case of missing data which could not be resolved by available case analysis, the corresponding author was contacted.

Patient and public involvement

Patients and the public were not involved in the design, or conduct, or reporting, or dissemination plans of our research.

RESULTS

Applications of indocyanine green fluorescence angiography in trauma surgery

The search yielded 773 results, of which 748 remained after deduplication. Based on title and abstract screening, 701 reports were excluded. One full-text report could not be retrieved. After a full-text assessment of eligibility, 13 studies were eligible for inclusion in the systematic review (figure 1). All studies were observational. Two studies were prospective, and five were retrospective, of which two were comparative.[12 21–26] The remaining six studies were case series or case reports including three or fewer patients, which were not included in the final analysis due to a low power of evidence based on study design.[27–32] The MINORS quality assessment score of

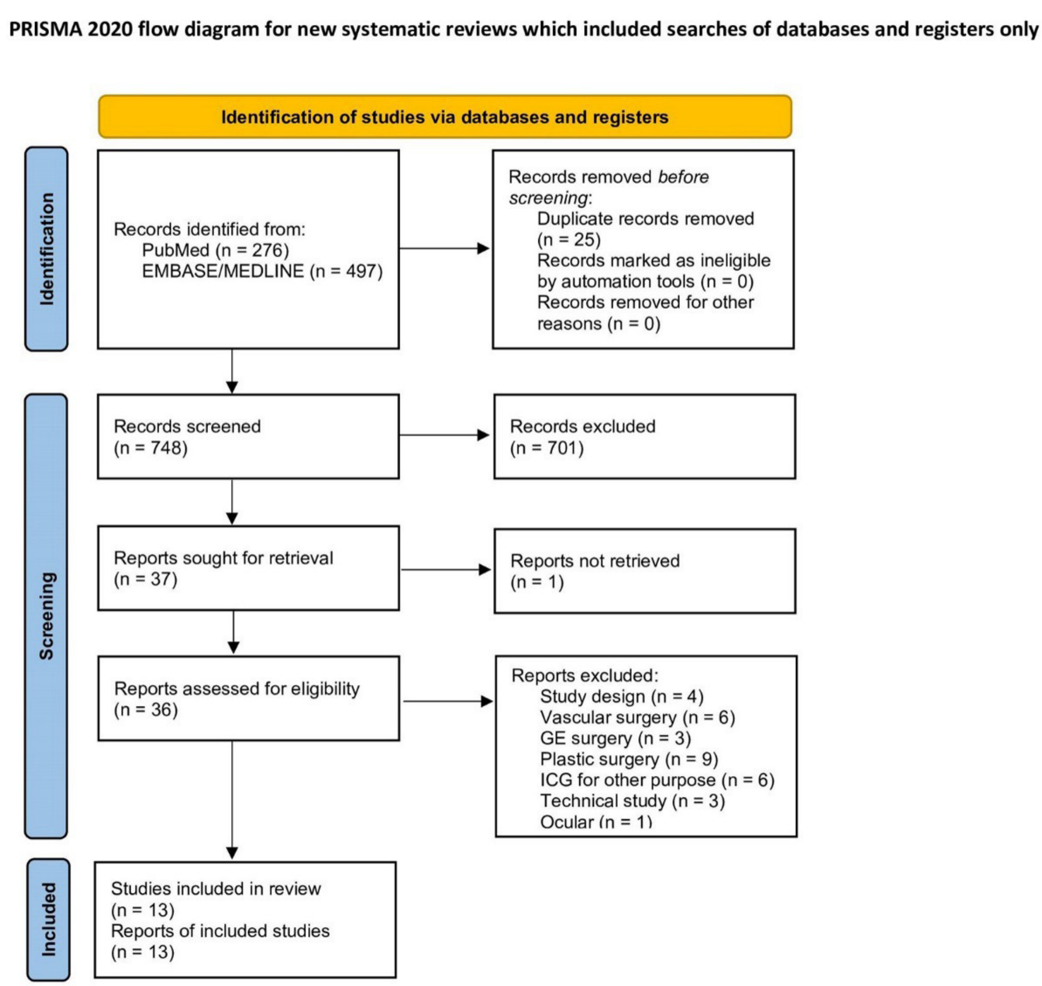

Figure 1 Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram of screening and inclusion process. ICG, indocyanine green.

included comparative studies ranged from 17 to 20, out of the maximum score of 24. The score for included non-comparative studies ranged from 9 to 14, out of the maximum score of 16 (online supplemental 3).

Results of the included studies are listed in table 1. All included studies reported on the use of ICG for perfusion assessment. In total, 301 patients were administered ICG for purposes related to the field of trauma surgery. All patients received ICG through intravenous injection. For safety outcomes, no ICG-related complications were reported in any of the included studies or available case reports. For treatment outcome, four out of seven studies reported whether ICG-FA caused changes in intraoperative decision-making with a range of 28.5% to 78.9%.[12 25 28 29] The results of case series/reports including three or fewer patients were not included in the final analysis but are listed in online supplemental 4, with their respective MINORS quality assessment listed in online supplemental 5. Four studies performed qualitative measurements, which are subjective.[22–24 26] Three studies performed quantitative measurements, namely, fluorescence intensity.[12 21 26] One study performed semi-quantitative measurements, namely, the difference in fluorescence intensity between the beginning and the end of the measurement.[25]

In the selected studies regarding extremity injury, ICG was reported to be useful for detection of necrotic tissue and determination of debridement margins.[12 21] In the comparative study by Koshimune *et al*, application of the technique resulted in a significant decrease in leftover necrosis (15.4% vs 60.0%), number of debridements (1.69 vs 2.7) and infection rates (7.6% vs 50%).[24] In the non-comparative study by Green 3rd *et al*, the intraoperative decision in amputation patients changed in 31.7% of cases. Notably, the change in intraoperative decision was lower but still present in extremity pedicle flaps (15.7%), extremity free flaps (12.5%) and craniofacial free flaps (15.4%).[12] ICG-FA was also deemed useful for determining the optimal timing of surgery, since diminished skin perfusion is associated with limited healing capacity of tissue. ICG may be used to assess whether tissue vitality has recovered enough to perform surgery, which was supported by the observation of tissue perfusion recovery with delayed fixation.[21] Interestingly, postoperative use of ICG for outflow assessment may also provide essential information, as poor outflow is also a sign of malperfusion with consequences for management of the injury.[33 34] Notably, Mothes *et al* described a difference in intraoperative and postoperative assessment. In microvascular repair, ICG had a significantly higher prognostic value than any of the clinical parameters (turgor, reperfusion, temperature and bleeding), but the intraoperative clinical parameters and ICG-FA were less consistent with the final outcome than those taken postoperatively. In microvascular tissue transplantation, intraoperative ICG had a higher sensitivity for flap loss than clinical parameters, but postoperative ICG did not.[25]

In abdominal trauma, ICG was beneficial to detect avital tissue and thus determine optimal resection locations, changing the intraoperative decision in 33.3% of patients in the study by Green 3rd *et al.*[12] Its use also decreased postoperative complications, such as anastomotic leakage, in abdominal trauma surgery from 38.5% to 9%.[23] Osterkamp *et al* described improved surgical management with changes in intraoperative decisions in 14 out of 20 patients, six of which were deemed significant.[22]

There were many practical differences between included studies such as fluorescence thresholds, quantified or qualified signal interpretation, variations in ICG type and dosage and use of different devices and interpretation software. For example, ICG doses widely varied, with some studies administering a fixed dose and some administering a weight-based dose of ICG to patients. Studies did not report why a fixed or weight-based dose was chosen nor the reason for choosing the dosage. These differences caused a high level of heterogeneity which largely decreased the comparability of included studies. An overview of practical characteristics of included studies is presented in table 2

When looking at the case series and case reports, ICG could highly benefit individual patients in comparison to visual vitality assessment. Afifi *et al* described a case of abdominal trauma in which 20 cm of non-perfused bowel was missed by visual assessment and detected using ICG. The segment was additionally resected, and the patient did not develop postoperative complications, whereas these would probably have presented if the non-perfused segment would have remained in the patient.[27] Pruimboom *et al* described a case of extremity trauma in which three debridements were performed. ICG-guided fluorescence in the form of near-infrared fluorescence was used for viability assessment of soft tissue postoperatively the first two times. During the third debridement, ICG was used in real time to guide the debridement procedure. There was no difference between the second and third ICG images, indicating that if the second debridement had been performed with ICG guidance, the final debridement would not have been necessary. The patient could thus have been spared an additional debridement.[32] As the authors stated, this case supports the use of ICG for detection of necrotic tissue and determination of debridement margins, which is in line with the findings of Koshimune *et al.*[24 32]

DISCUSSION

Trauma is a disease, and a challenge in multiple anatomic regions is to determine tissue viability after injury. ICG may assist in this vitality assessment. In literature, one review is available regarding ICG in emergency general surgery,[33] and one narrative review regarding the use of ICG in trauma and surgery was found.[35] However, to the authors' knowledge, no previous systematic reviews regarding trauma-specific use of ICG have been published. This paper presents an overview of current applications of ICG in trauma surgery, including its impact on clinical

Table 1 Characteristics and outcome data of included studies

Study	Study design	N	ICG for trauma purposes (n, %)	Traumatic injury (n)	Dose of ICG	ICG-based change in decision	Benefit of ICG	ICG-related complications
Sepehri 2021[21]	Prospective, non-comparative	27	27 (100%)	Pilon fracture (n=8), tibia plateau fracture (n=19)	0.4 mL (2.5 mg/mL)	N/R	None (observational: feasibility study of ICG-guided assessment of severity of soft tissue injury)	None reported
Osterkamp 2021[22]	Prospective, non-comparative	20	20 (100%)	Stab or gunshot wounds to bowel	5 mg	14 (70%)	Improved surgical management (six out of 14 changes were deemed significant)	None
Yamaguchi 2021[23]	Retrospective, comparative	37	11 (29.7%)	Intestinal trauma	0.25 mg/kg	N/R	Decrease in rate of postoperative complication (9% vs 38.5%)	None
Koshimune 2017[24]	Retrospective, comparative	23	13 (56.5%)	Gustilo IIIB open lower limb fracture	0.2 mg/kg	N/R	Significant decreases in: ► Leftover necrosis (15.4% vs 60%) ► No. of debridements (1.69 vs 2.7) ► Infection (7.6% vs 50%)	None reported
Green III 2015[12]	Retrospective, non-comparative	186	186 (100%)	Combat-related: extremity free flap (72), extremity pedicle flap (51), amputation and revision (41), craniofacial free flap (13) and abdominal/ gastrointestinal (9)	7.5 mg (2.5 mg/mL)	35 (28.5%)	Improved intraoperative decision-making	None reported

Continued

Table 1 Continued

Study	Study design	N	ICG for trauma purposes (n, %)	Traumatic injury (n)	Dose of ICG	ICG-based change in decision	Benefit of ICG	ICG-related complications
Mothes 2004[25]	Retrospective, non-comparative	25	25 (100%), with 91 ICG measurements	Microvascular repair of hand/lower arm (n=14, number of measurements=43), free flap surgery (n=11, number of measurement=48)	0.5 mg/kg	43 (47.2%)*	Compared with clinical parameters: ► In microvascular repair: significantly higher prognostic value in cases of postoperative tissue necrosis ► In free flap surgery: higher sensitivity for flap loss	None reported
Han 2022[26]	Retrospective, non-comparative	19	19 (100%)	Paediatric skin and soft tissue trauma	2.0–4.0 mL (2.5 mg/mL, max. 0.5 mg/kg	15 (78.9%)	No postoperative necrosis in 18 (94.7%) patients	None reported

*Percentage is calculated based on total number of ICG measurements.
ICG, indocyanine green; N/R, not reported.

Table 2 ICG-specific characteristics of included studies

Study	Distance to tissue	ICG dose	ICG type	Fluorescence device	Measurement type	Parameter	Analysis software	Lower limit of adequate perfusion
Sepehri 2021[21]	N/R	0.4 mL (2.5 mg/mL)	N/R	SPY Elite Fluorescence Imaging System (Stryker)	Quantitative	Fluorescence brightness (0–255 fu)	JMP Pro V.13	Not determined yet
Osterkamp 2021[22]	N/R	5 mg	Verdye (Diagnostic Green)	SPY-PHI Elite Imaging System (Stryker)	Qualitative	N/R	N/A	N/R
Yamaguchi 2021[23]	N/R	0.25 mg/kg	N/R	HyperEye Medical System (MIZUHO Medical)	Qualitative	Time to perfusion	N/A	Time to perfusion <60 s
Koshimune 2017[24]	N/R	0.2 mg/kg	Diagnogreen (Daiichi-Sankyo)	PDE-neo (Hamamatsu Photonics)	Qualitative	Fluorescence progression in early phase (~10 s from start of fluorescence enhancement)	N/A	N/R
Green III 2015[12]	N/R	7.5 mg (2.5 mg/mL)	N/R	SPY and subsequent SPY Elite systems (LifeCell/ Novadaq)	Quantitative	Fluorescence intensity: relative-percentage (0%–100%) and absolute (0–255 fu)	SPY-Q	25% (relative-percentage)/6.0 fu
Mothes 2004[25]	30–100 cm	0.5 mg/kg	ICG-Pulsion	IC-VIEW system (Pulsion Medical Systems)	Semiquantitative	► Comparison of clinical parameters of turgor, temperature and capillary perfusion to those of normal surrounding tissue ► Difference in fluorescence intensity between beginning and end of measurement	N/R	► N/S ► >10% difference in fluorescence intensity

Continued

Table 2 Continued

Study	Distance to tissue	ICG dose	ICG type	Fluorescence device	Measurement type	Parameter	Analysis software	Lower limit of adequate perfusion
Han 2022[26]	N/R	2.0–4.0 mL (2.5 mg/mL, max. 0.5 mg/kg	ICG (Dandong Yichuang)	Specific model: N/S (Mingde Medical Diagnostics)	▲ Qualitative (intraoperative) ▲ Quantitative (postoperative)	▲ Qualitative: not specified ▲ Quantitative: tissue perfusion intensity at random point	Vascular imaging software (V.1.0, Mingde Medical Diagnostics)	▲ Qualitative: general condition of traumatic wound ▲ Quantitative: <33% of maximal perfusion

Fu, fluorescence units; ICG, indocyanine green ; N/A, not applicable; N/R, not reported; N/S, not specified.

outcomes. This systematic search of literature yielded 13 studies regarding the use of ICG in trauma surgery, six of which were case reports. ICG was used for vitality assessment in all available studies. The indications for use were, in general, traumatic extremity injury to bones and soft tissue and traumatic abdominal injury. In all studies, ICG was used to detect avital tissue and assist in intraoperative decision-making during debridement procedures or bowel resection with the goal of lowering the number of surgical procedures and postoperative complications such as leftover necrosis and infection. None of the included studies reported disadvantages to the use of ICG or complications or adverse events related to ICG.

Even when combining the results on extremity and abdominal trauma surgery, the amount of available literature was limited. Still, the use of ICG in trauma surgery so far looks promising. All the included studies reported beneficial effects, from confirmation to improvement of surgical decision-making. This technique could increase surgical accuracy, as illustrated by the reported percentages of change in intraoperative decision-making, ranging from 28.5% to 78.9%.[12 22 25 26] This may result in improvement of postoperative outcomes.[23 24] ICG was successfully used in extremity injury for detection of avital tissue, determination of resection margins and reduction of the number of necessary debridement procedures.[12 21 24 26 28–32] It was also used for postoperative detection of poor outflow.[30] In abdominal trauma surgery, ICG was beneficial to detect malperfused tissue, thereby enabling the surgeon to determine optimal resection locations.[12 22 23 27] In both types of injury, ICG caused a decrease in postoperative complications.

Keeping in mind these benefits of ICG in trauma surgery for both blunt and penetrating trauma, it must be noted that the intraoperative decision will not change in every patient, as experienced surgeons can accurately assess the vitality of tissue in most patients. However, this is no reason for scepsis since the extra information provided by ICG can make a difference in difficult cases which every surgeon encounters. With a range of changes in intraoperative decisions from 28.5% to 78.9%**,** the available studies clearly show an added benefit of ICG over visual assessment studies. However, the included studies have two general limitations. First, all studies are based on either qualitative measurements, which are inherently subjective, or suboptimal quantitative measurements. The available quantitative measurements were all based on fluorescence intensity, which is dependent on external factors and hard to reproduce. It is a good parameter for intrapatient measurements, but not for interpatient comparison.[34] Intensity parameters are inconsistent in clinical settings and sensitive to practical differences between patients, thus also between studies. Inflow parameters such as T^0 (time to first fluorescence signal), $T_{1/2max}$ (time to half of the maximum fluorescence) and T_{max} (time to maximum fluorescence) are more independent and thus more reliable and comparable between patients and studies.[36] Such reliable inflow parameters were not used in any of the included studies. Second, the number of available studies is limited, sample sizes are small and the studies are not generalisable. There are many differences between studies such as indications for ICG, outcome measurements, fluorescence thresholds, signal interpretation, ICG type and dosage, devices and interpretation software. These are critical aspects which are essential to report. The suboptimal parameters, with a complete lack of use of quantitative inflow parameters and practical differences, decrease the possibilities to objectify, validate and compare studies, as well as the possibility to decide on the adoption of ICG.

When thinking of the application of ICG in trauma surgery, two important questions may arise. The first one is related to duration. In our experience, after intravenous administration of ICG, it first shows the arterial flow and then the venous flow, all within a timeframe of minutes. Comparing this added time to the time that may be spent doubting on resection or debridement margins during difficult procedures, this may not even be a true extension of procedure duration. The second question is related to the time needed to master this technique as a surgeon. In general, trauma surgeons are skilled and experienced in visual assessment, and a new technique usually takes time to master. However, Osterkamp *et al* tested the system usability of ICG in abdominal surgery by means of a System Usability Scale (SUS) questionnaire after each procedure.[37] The higher the SUS score, the greater the usability of a system. The median first-time SUS was 68.8, which increased to 82.5 after three procedures. Notably, all surgeons agreed (score of four out of five) that the system was easy to use; they would like to use it frequently, functions were well-integrated within the system, and they thought most people would learn to use the system very quickly.[22]

The limited availability of existing literature in this field highlights that future topics of trauma-related application of ICG are still broad. For example, ICG may also be the only available technique for effective monitoring of vascularised bone grafts, although this still must be confirmed in human studies.[38] Furthermore, ICG was already used in combat-related extremity and abdominal trauma by Green 3rd *et al*, who concluded that ICG can provide essential information within several minutes.[12] Besides, with handheld camera models being already available, the technique could be suitable for application in low resource environments. Last, its use is also safe and feasible in very young patients.[39] As one of the included studies shows, it can also be used in acute paediatric trauma to reduce the risk of postoperative necrosis and assist to make decisions regarding skin sparing.[26]

This article has several limitations. Since most included studies are retrospective and non-randomised, this systematic review is subject to a high risk of bias. Although the articles were assessed for quality and none of the included studies scored less than 50% of its maximum MINORS score, the study designs do not warrant a scientifically rigorous conclusion. The combination of results regarding abdominal and extremity trauma is also suboptimal, but necessary due to limited availability of studies. Furthermore, the large heterogeneity between included studies, their practical conditions and their reported data limits possibilities for meta-analysis. Moreover, the findings of a database search are in general subject to publication bias. In this review, one should be especially cautious of potential publication bias as no negative reports on ICG-FA in trauma surgery were found. Since the use of fluorescence is still new in the field of trauma surgery, articles are more likely to be submitted for publication if the new technique shows promising results. Nevertheless, the number of changes in intraoperative decisions as well as improvement rates of postoperative outcomes described across the included studies shows the potential of ICG-FA for better and more efficient treatment of trauma patients. Therefore, further prospective research with larger sample sizes, identical practical conditions and solid quantification parameters is necessary to be able to decide on the adoption of ICG based on the literature that is currently available.

Implications for future research

This systematic review provides several recommendations for future research on ICG-FA in trauma surgery. First, to ensure objective and reliable results, prospective multicentre studies with large sample sizes are recommended. Second, to ensure comparability of research and to obtain targeted results on the benefits of ICG-FA for specific subtypes of trauma surgery, results should be stratified by trauma region (eg, abdominal vs extremity) and by the specific aim of ICG (eg, anastomosis, soft tissue viability or bone viability). Third, any future studies should implement standardised protocols, including clearly justified choices for ICG dosage, timing of administration and assessment parameters. The assessment parameters should be validated, quantified inflow parameters such as T_{max} and T_0, thus increasing reliability and allowing for comparison between patients and studies. The step-by-step World Society of Emergency Surgery (WSES) protocol for ICG-FA in the emergency setting may be a helpful starting point.[40] Finally, the influence of factors such as tissue oedema and vasopressor use on the ICG signal remains unclear. Since ICG binds to plasma proteins such as albumin after intravenous administration, these factors could potentially affect the signal. If so, they should be taken into account when interpreting the ICG signal. It is highly recommended to investigate this potential effect in future studies.

CONCLUSION

Trauma is a condition that can affect multiple body regions. All the included studies reported beneficial effects such as the detection of avital tissue, determination of resection/debridement margins, reduction of debridement procedures and detection of poor postoperative outflow. In both traumatic extremity and abdominal injury, ICG caused a decrease in postoperative complications. ICG caused a change in intraoperative decision in many studies, with a range of 28.5% to 78.9% in the included studies. None of the included studies reported any ICG-related complications or adverse events.

However, it should be kept in mind that only a limited number of studies are available regarding the use of ICG-based fluorescence techniques in trauma surgery, and their comparability is low due to practical differences. Due to the limited number of available studies, small sample sizes and heterogeneity between the included studies precluding the possibility of meta-analysis, the results of this review do not allow a general conclusion on the applications and effects of ICG in trauma surgery. Nevertheless, the promising results show the potential of ICG-FA for better and more efficient treatment of trauma patients. Further research with larger sample sizes and comparable practical conditions is thus not only necessary but highly recommended.

Contributors Conception and study design: EAB, EJdF, FH and JR. Screening and selection: EAB and EJdF. Critical appraisal: EAB and EJdF. Data acquisition: EAB and EJdF. Data analysis and interpretation: EAB, DDK, FH and JR. Drafting of the manuscript: EAB, EJdF, DDK, KvW, IGdB, FH and JR. Critical revision: EAB, EJdF, DDK, KvW, IGdB, FH and JR.Guarantor: EAB.

Funding The authors have not declared a specific grant for this research from any funding agency in the public, commercial or not-for-profit sectors.

Competing interests None declared.

Patient and public involvement Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Patient consent for publication Not applicable.

Ethics approval Not applicable.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data sharing not applicable as no datasets generated and/or analysed for this study. As the results of this systematic review are purely descriptive, no further analysis was performed. All data to support the findings of this study are available in the data tables and supplementary materials.

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